Universität Freiburg
Advanced physics lab, part 1
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Experiment 5
Acousto-optic modulator

[redacted]
(Group 11)

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Tutor: [redacted]

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1 Goal of the experiment

The goal of this experiment is to measure how a change in frequency or amplitude of an acoustical wave can change the behaviour of a laser beam. Furthermore the speed of the sound wave in the crystal is calculated.

2 Experiment

2.1 Setup

In this experiment an acusto-optic modulator(AOM)[1] is used to change the laser beam of a 532 nm-laser[2].

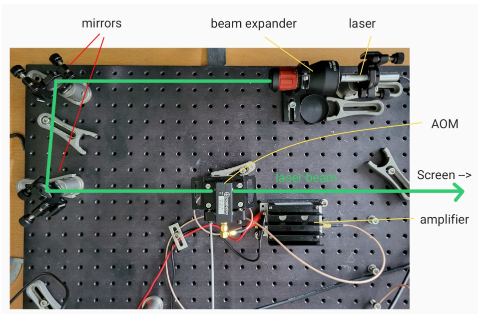


Figure 1: Setup for the frequency measurement

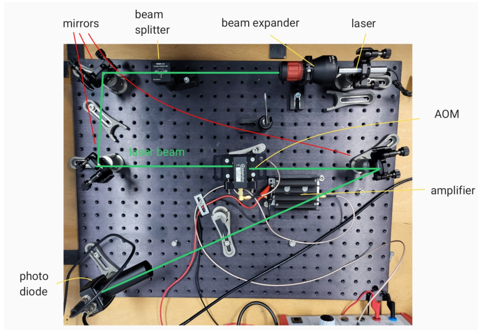


Figure 2: Setup for the amplitude measurement

For the measurement of the influence of the frequency applied to the acoustic wave in the AOM-crystal on the laser beam the setup in figure 1 is used. For the measurement of the influence of the amplitude from the acoustic wave on the laser beam the setup in figure 1 is used. The beam splitter was used to achieve sharper peaks. The amplifier of the AOM is powered by a constant voltage and triggered with a function generator. For the amplitude measurement the laser signal is detected by a photodiode. The signal of the photodiode is analysed on a connected oscilloscope.

2.2 Execution

For the first measurement of the influx of the trigger frequency the laser beam is diffracted in the AOM and analysed on a screen in a certain distance. For the amplitude changes and the measurement of the rise time from a laser pulse the data is collected on the oscilloscope. Therefore, the pulses are created on the function generator.

3 Evaluation and error analysis

3.1 changing the AOM trigger frequency

The trigger sine frequency of the AOM is changed in a range from $f = 20\,\mathrm{MHz}$ to $f = 100\,\mathrm{MHz}$ in $f = 5\,\mathrm{MHz}$ steps. The different frequencies lead to different diffraction indices in the AOMs TeO_2-crystal[1] and therefore to to various distances between the peaks of diverse orders.
The distance between the AOM and the screen is $122.5\,\mathrm{cm} \leq d \leq 124.7\,\mathrm{cm}$ because the size and position of the Tellurium Dioxide crystal inside the AOM is not known. The values are the the distances from the screen to the front and back of the AOM casing. As the distance to calculate with, the mean value is taken with an error half of the distance between the two value rectangular distributed. With $a_\mathrm{d} = 1.1\,\mathrm{cm}$ the uncertainty is $\Delta d = \frac{1.1\,\mathrm{cm}}{\sqrt{3}} \approx 0.6\,\mathrm{cm}$. Finally

$$d = (123.6 \pm 0.6)\,\mathrm{cm}.$$

The distance between the distance between different order peaks is measured from the -3rd to the 3rd order peak on the screen with millimeter paper. As an example, this is illustrated in figure 3 for $f = 80\,\mathrm{MHz}$.

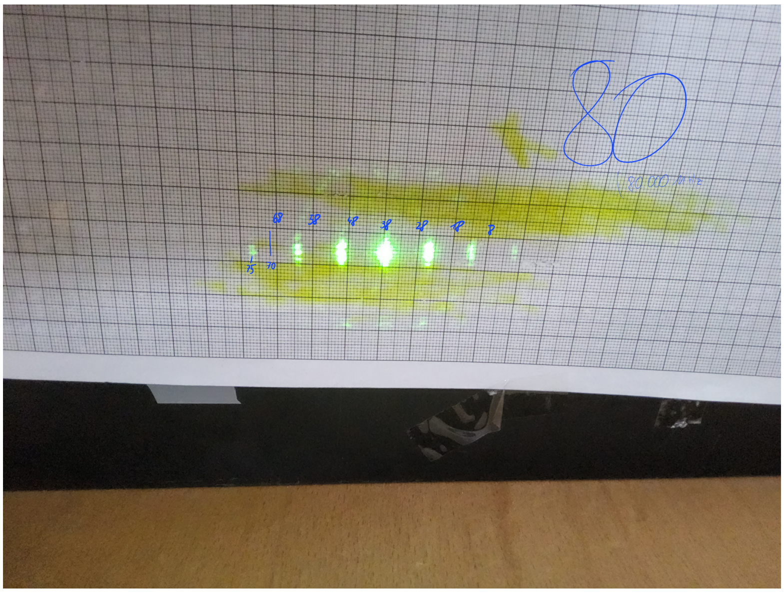


Figure 3: Screen with Raman-Nath regime for trigger frequency $f = 80\,\mathrm{MHz}$

The error is estimated by $a_x = 1\,\mathrm{mm}$ triangularly distributed. The uncertainty follows with $\Delta x = \frac{1\,\mathrm{mm}}{\sqrt{6}} \approx 0.4\,\mathrm{mm}$. In figure 4 the diffraction angle θ between the 0th 1st order peak is shown depending on the trigger frequency in the crystal.

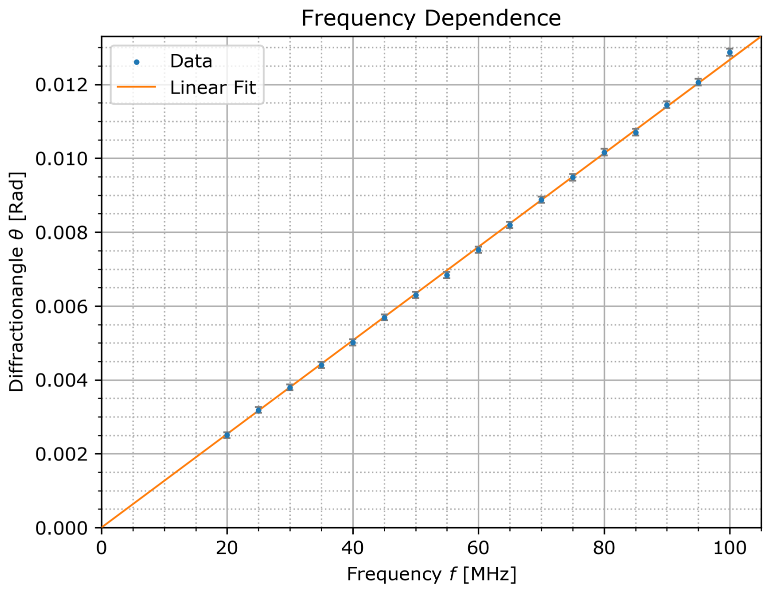


Figure 4: Diffraction angle θ from 1st order peak to 0th order peak

Here in figure 4 the data points are plotted with their error bars and a linear fit $x = c_1 \cdot f$ is shown. In figure 5 the residues of the values are shown with the fit and its uncertainty. With a reduces χ^2 of $\chi^2/\mathrm{ndf} = 0.61$ it is clear that the fit has a great quality but the errors were estimated to big. Only a few values vary significantly from the fit.

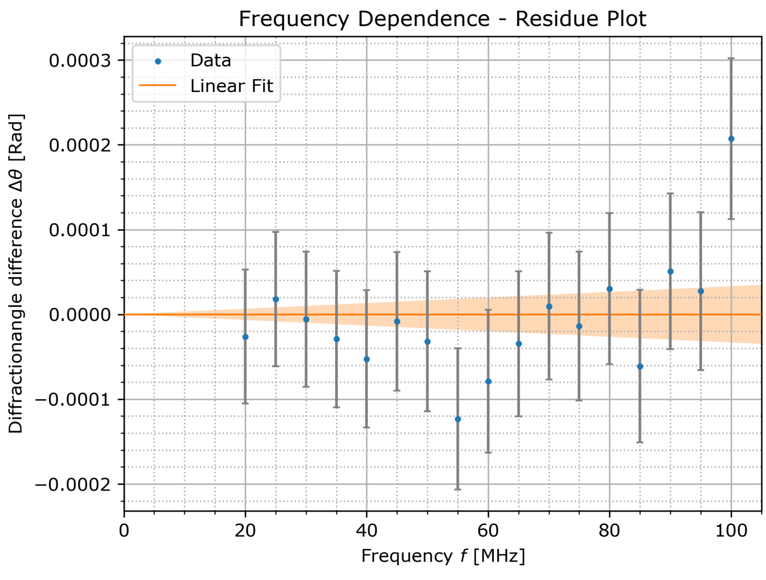


Figure 5: Residue plot for figure 4

With the distances d and x the diffraction angle θ is calculated with $\theta = \arctan(\frac{x}{d})$. This is twice the incoming Bragg angle $\theta = \Theta_\mathrm{B}$. The speed v of the sound wave in the AOM can be calculated by the formula[3]

$$\theta = \frac{\lambda f}{v} = c_1 f.$$

From the slope and the wavelength, the speed v is calculated to

$$v = (4200 \pm 11)\,\mathrm{m/s}.$$

3.2 Changing the AOMs amplitude

In the measurement with the setup in figure 2 the influx of a change in the amplitude of the acoustic wave on the laser beam is analysed. For that the 1st order peak is detected with the photodiode. The data is then collected by an oscilloscope. As an error on these values $\pm 3\,\%$ of the value is taken because there was a lot of noise in the signal. This noise was much bigger than the uncertainties of the used devices For the trigger, a rectangular frequency with $f_\mathrm{r} = 50\,\mathrm{Hz}$ was laid over the sine frequency set to $f_\mathrm{s} = 80\,\mathrm{MHz}$. The amplitude was modulated from $U = 0\,\mathrm{V}$ to $U = 5\,\mathrm{V}$ in $0.2\,\mathrm{V}$ steps. This is shown in figure 6. With that measurement the voltage ran into a $U \approx 500\,\mathrm{mV}$ border. Therefore only values for $U = 3.2\,\mathrm{V}$ were used.

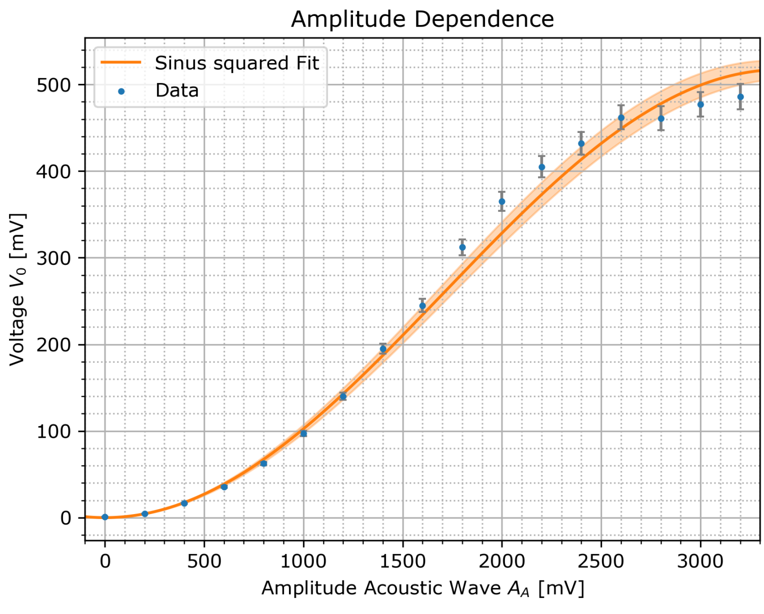


Figure 6: Voltage measured on the oscilloscope from the photodiode depending on the amplitude of the acoustic wave.

In figure 6 the data points and their error bars are illustrated and fitted. The fit is described through the function[3]

$$I_1 = I_0 \sin^2(\sqrt{\eta}) = I_0 \sin^2\left(n\sqrt{\frac{1}{\lambda_0^2}\frac{L}{H}M_2 P_\mathrm{a}}\right).$$

Where I_1 is the intensity of the examined 1st order peak, η is the efficiency, $n = 2.22$ the refractive index, M_2 the figure of merit, $\frac{L}{H}$ the ratio between length and height of the area with the sound field and P_a the acoustical power. The Fit is done on the voltage V_O for the Voltage given on the oscilloscope depending on the amplitude A_A from the acoustic wave generator. This is possible because $V_0 \propto I_1$ and $A_A \propto \sqrt{P} \propto \sqrt{\eta}$. With a reduced χ^2 of $\chi^2/\mathrm{ndf} = 78$.

3.3 Rise time of the pulsed laser peak

The rise time t_R is measured with the same setup as the amplitude on the oscilloscope. The rise time was measured with the photodiode turned on and off. With the diode on the rise time is

$$t_\mathrm{R,on} = 307.3\,\mu\mathrm{s}$$

and with the diode turned off

$$t_\mathrm{R,off} = 35.59\,\mu\mathrm{s}.$$

(As there was no $50\,\Omega$ resistor used at the oscilloscope end of the photodiode, the results are not deemed reliable and therefore no errors are estimated, more on that in section 4.2.3.) Compared to that the rise time of the photodiode is $t_\mathrm{R,diode} = 1\,\mathrm{ns}$ and therefore it does not make a difference in the result.
The speed of the sound wave can be again be calculated by

$$T_R = 0.64 D/v$$

[3] with the diameter D of the laser beam. It has a given diameter of $D_0 = 3.5\,\mathrm{mm}$[2]. With the beam expander the beam can be narrowed down five times[4] to $D = 0.7\,\mathrm{mm}$. At the end v is calculated to

$$v_\mathrm{on} = 1.458\,\mathrm{m/s}$$

and

$$v_\mathrm{off} = 12.588\,\mathrm{m/s}.$$

4 Discussion

4.1 Final results

From the measurement with changing frequencies the speed of the sound wave in the AOM crystal is

$$v = (4200 \pm 11)\,\mathrm{m/s}.$$

The rise times of the detected peak is

$$t_{\mathrm{R,on}} = 307.3\,\mu\mathrm{s}$$

with the diode turned on and

$$t_{\mathrm{R,off}} = 35.59\,\mu\mathrm{s}$$

with the diode turned off. From the rise time the sound wave speed is calculated to

$$v_{\mathrm{on}} = 1.458\,\mathrm{m/s}$$

with the diode turned on and

$$v_{\mathrm{off}} = 12.588\,\mathrm{m/s}$$

with the diode turned off.

4.2 Comparison with expected results

4.2.1 changing the AOM trigger frequency

The literature value of the sound speed in Tellurium Dioxide crystal[5] is

$$v_{\mathrm{lit}} = (4202 \pm 1)\,\mathrm{m/s}$$

When the measured value $v = (4200 \pm 11)\,\mathrm{m/s}$ is compared with the literature a t-test

$$t = \frac{|\ \hat{x} - \hat{y}\ |}{\sqrt{(\Delta x)^2 + (\Delta y)^2}}$$

can be made. Here $t \approx 0.2 < 2$ states that the value is compatible with the literature. This is supported by the good χ^2 value.

4.2.2 Changing the AOMs amplitude

The fit done, for the first maximum intensity does not fit particularly well. This is reflected in the $\chi^2/\mathrm{ndf} = 78$ value. The probable reason for that is the stagnation of the intensity for acoustic amplitudes $A \geq 3.2\,\mathrm{V}$. This stagnation is not entirely understood, a possible cause could be, that the high frequency amplifier was maxed out, or that the photodiode was not working properly. A strong indication of the photodiode not working was that, even when there was a clear and strong light beam on the diode, it only showed minimal current on the oscilloscope. That is the reason the $1\,\mathrm{M}\Omega$ end resistance from the oscilloscope was used in the measurements.

4.2.3 Rise time of the pulsed laser peak

The literature value of the rise time of the laser peak[1] is

$$t_{\mathrm{R,lit}} = 77\,\mathrm{ns}$$

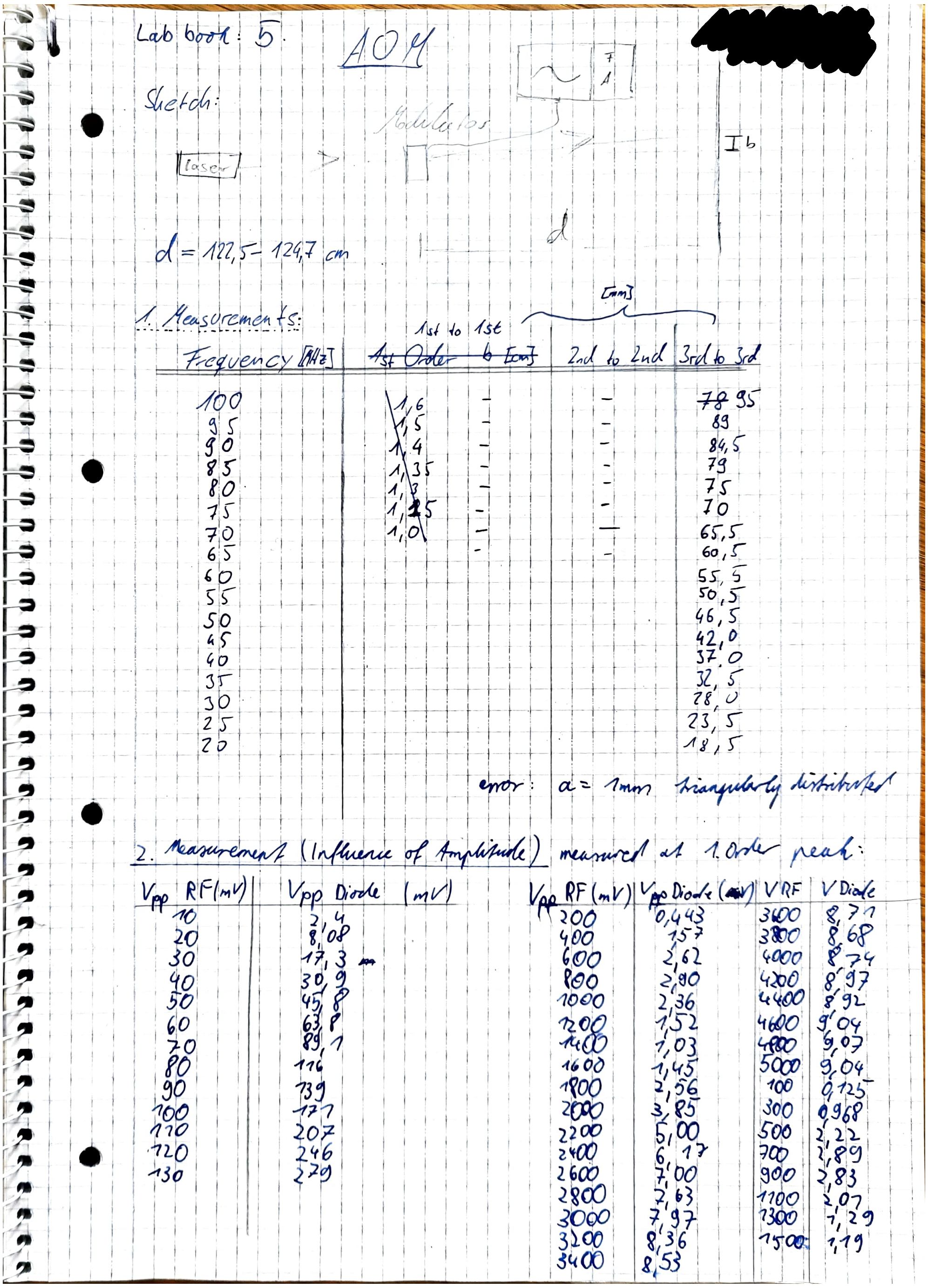
for a laser beam diameter of $D = 0.5\,\mathrm{mm}$. The measured values are far away from the literature value and so is the resulting calculated speed of sound. This was expected because no additional $50\,\Omega$ resistance was used at the connection to the oscilloscope. But it would be necessary to use because of the $1\,\mathrm{M}\Omega$ input impedance of the oscilloscope. The problem was with the extra resistance no signal could be detected at all. So again that indicates there might have been a problem with the photodiode.

4.3 Improved methods

The literature values from the data sheet[1] are for the AOM model ATM-80A1. But in the experiment the AOM ATM-801A1 was used. So maybe the values are not correct for the setup used. In the other Instruction manual[3] for the ATM-801A1 other values are mentioned, but the serial number does not fit and at the end it is said that an other model (ASM-801A1) with the same serial number was tested. therefore it is not clear to which AOM the whole text refers.
For a better experiment it would help to know exactly what characteristics the used devices have. Furthermore the photodiode should work better to be able to get a detectable signal on the oscilloscope.

5 Attachment

5.1 Lab book



Lab book: 5. [redacted]

AOM

Sketch:

$d = 122{,}5 - 124{,}7$ cm

1. Measurements:

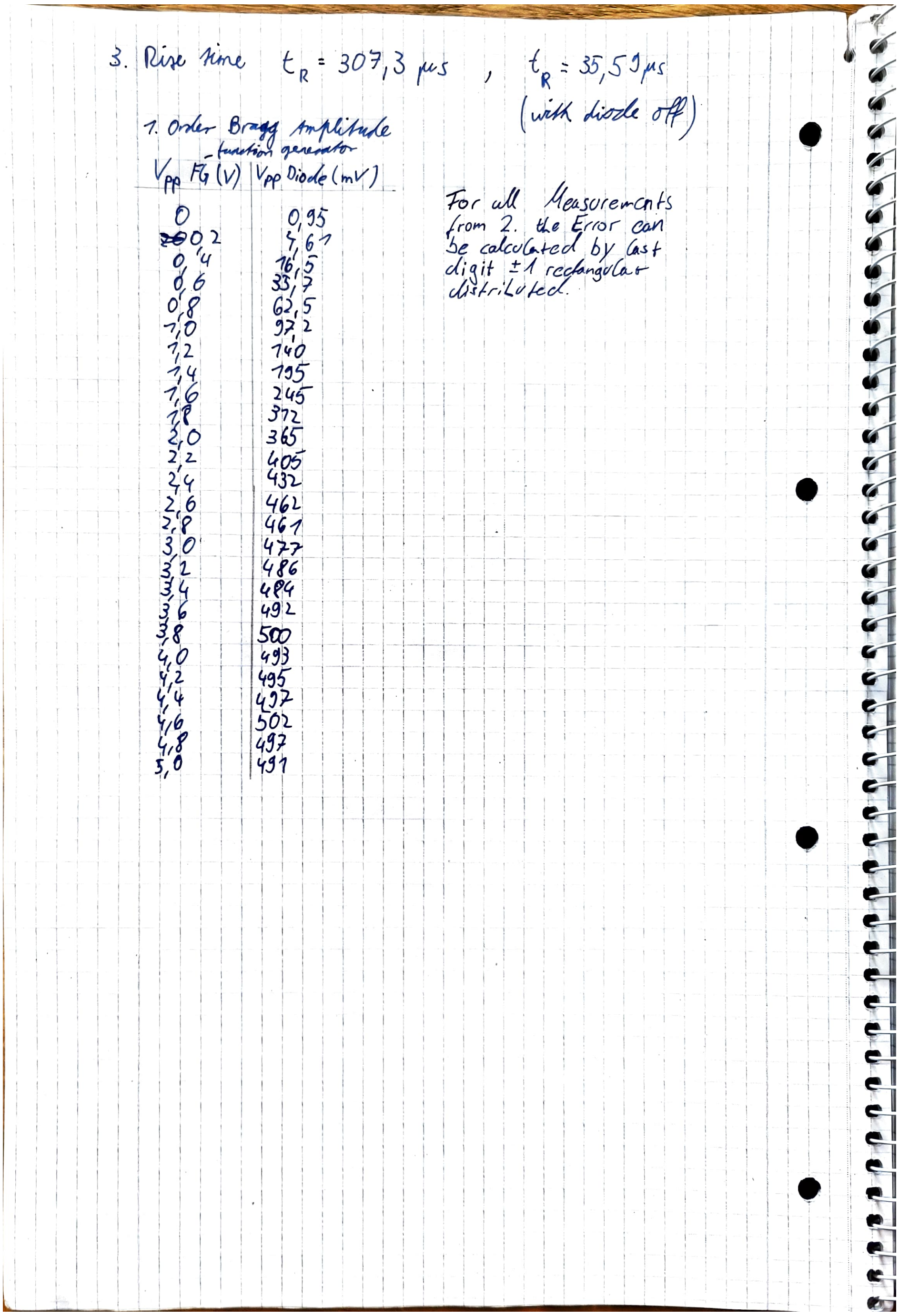
Frequency [MHz]	~~1st Order~~	1st to 1st [cm]	2nd to 2nd [mm]	3rd to 3rd [mm]
100	~~1,6~~	–	–	~~78~~ 95
95	~~1,5~~	–	–	89
90	~~1,4~~	–	–	84,5
85	~~1,35~~	–	–	79
80	~~1,3~~	–	–	75
75	~~1,25~~	–	–	70
70	~~1,0~~	–	–	65,5
65		–	–	60,5
60				55,5
55				50,5
50				46,5
45				42,0
40				37,0
35				32,5
30				28,0
25				23,5
20				18,5

error: $a = 1$ mm triangularly distributed

2. Measurement (Influence of Amplitude) measured at 1. Order peak:

V_{pp} RF (mV)	V_{pp} Diode (mV)
10	2,4
20	8,08
30	17,3
40	30,9
50	45,8
60	63,8
70	89,1
80	116
90	139
100	177
110	207
120	246
130	279

V_{pp} RF (mV)	V_{pp} Diode (V)	V RF	V Diode
200	0,443	3600	8,71
400	1,57	3800	8,68
600	2,62	4000	8,74
800	2,90	4200	8,97
1000	2,36	4400	8,92
1200	1,52	4600	9,04
1400	1,03	4800	9,07
1600	1,45	5000	9,04
1800	2,56	100	0,125
2000	3,85	300	0,968
2200	5,00	500	2,22
2400	6,17	700	2,89
2600	7,00	900	2,83
2800	7,63	1100	2,07
3000	7,97	1300	1,29
3200	8,36	1500	1,19
3400	8,53		



3. Rise time $t_R = 307,3\ \mu s$, $t_R = 35,59\ \mu s$ (with diode off)

1. Order Bragg Amplitude
– function generator

V_{pp} FG (V)	V_{pp} Diode (mV)
0	0,95
~~20~~ 0,2	4,61
0,4	16,5
0,6	33,7
0,8	62,5
1,0	97,2
1,2	140
1,4	195
1,6	245
1,8	312
2,0	365
2,2	405
2,4	432
2,6	462
2,8	461
3,0	477
3,2	486
3,4	484
3,6	492
3,8	500
4,0	493
4,2	495
4,4	497
4,6	502
4,8	497
5,0	491

For all Measurements from 2. the Error can be calculated by last digit ±1 rectangular distributed.

Figure 7: Lab book

literature

[1] IntraAction-Corp. “Model atm series acousto-optic modulator.” (2023), [Online]. Available: https://intraaction.com/wp-content/uploads/2023/06/ATMModSeries08991.pdf (visited on 09/16/2024).

[2] Thorlabs. “Cps532-c2 - collimated laser-diode-pumped dpss laser module, 532 nm, 0.9 mw, round beam, ø11 mm housing.” (2024), [Online]. Available: https://www.thorlabs.com/thorproduct.cfm?partnumber=CPS532-C2 (visited on 09/18/2024).

[3] IntraAction-Corp., *Model atm-801a1 acousto-optic modulator s/n 444874 instruction manual*, Sep. 10, 2015.

[4] Thorlabs. “Gbe05-a - 5x achromatic galilean beam expander, ar coated: 400 - 650 nm.” (2024), [Online]. Available: https://www.thorlabs.com/thorproduct.cfm?partnumber=GBE05-A (visited on 09/18/2024).

[5] L. Hangzhou Shalom Electro-optics Technology Co. “Teo2 crystals for ao application.” (2024), [Online]. Available: https://shalomeo.com/Laser-Crystals-and-Components/EO-Crystals-and-AO-Crystals/TeO2-Crystals-AO%20/product-281.html (visited on 09/18/2024).